New laser energy deposition algorithm for the RALEF-2D code*

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Correct modeling of the laser beam evolution and power deposition on unstructured grids is a computationally and numerically challenging task. The first goal for a new algorithm for the radiation-hydrodynamics code RALEF-2D [1] is the calculation of the refracted laser light distribution with minimal numerical diffusion. Therefore a long characteristics approach is applied. The incoming laser beam intensity is spatially discretized into single rays being traced through the computational grid. On the basis of the eikonal equation in geometrical optics [2] the equation of motion of a ray [3] in the undercritical regime, $n_e \ll n_c$, becomes $d^2\vec{x}/dt^2 = -(c^2/2)(\vec{\nabla}n_e/n_c)$. Continuous transitions of the ray trajectories up to the first spatial derivative between the numerical cells are guaranteed by the division of the original two-dimensional quadrilateral grid into triangles. Within each triangle the free electron density $n_e(\vec{x})$ then is uniquely defined piecewise linear by the vertex-centered values n_e and the gradients $\vec{\nabla}n_e$. Inside each triangle a ray with incoming power P_0 deposits the power $P_{dep} = P_0\,(1 - e^{-\kappa})$ given the optical depth $\kappa = \Delta s\ \mathrm{Im}\,(\sigma)$. Here Δs is the length of the ray segment, $\Delta s = \int_0^{\Delta t} c\,\sqrt{1 - n_e\,[\vec{x}\,(t)]\,/n_c}\;dt$, Δt the corresponding transition time, and σ the complex refractive index (per unit length) of the associated quadrilateral cell calculated by Kramers' inverse bremsstrahlung formula.

Figure 1 shows the mesh setup and two simulated ray trajectories for a quadratic density trough test case [3]. With the density profile $n_e(y) = (2n_c/l_y^2)(y^2 - l_y y + l_y^2/2)$, the mesh heigth $l_y = 100$ mm, the temperature dependence $T(y) \propto (n_e(y)/n_c)^{2/3}$, and a fixed Coloumb logarithm and ionization, analytical solutions for the cosine-shaped trajectories and their optical depth exist. The dimensionless trajectory error ϵ_T at the mesh exit point and the relative error ϵ_P in the summed-up deposited powers as functions of the number of quadrilateral cells in the y-direction N_y for a quarter cosine-wavelength are shown in Figure 2.

The second goal for the new algorithm is the calculation of the deposited and reflected powers and the angular distribution of the reflected laser light close to and above the critical free electron density ($n_e \gtrsim n_c$), e.g. at the surface of a solid metal. Therefore the raytracing algorithm is augmented by an one-dimensional wave optics solver for the wave propagation and energy deposition in a stratified medium [2]. A geometrical optics ray can split up into an "overcritical" wave optics ray propagating perpendicular to the critical surface and a reflected geometrical optics ray. Further test simulations will be conducted soon.

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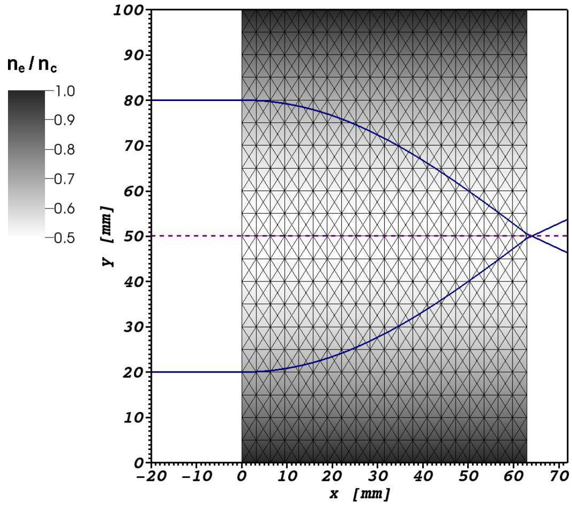

Figure 1: Mesh setup and two simulated ray trajectories for a quadratic density trough test case [3] with mesh heigth $l_y = 100$ mm. Trajectory entry points: $y_a = 20, 80$ mm; analytical trajectory exit point: $y_e^{an} = 50$ mm.

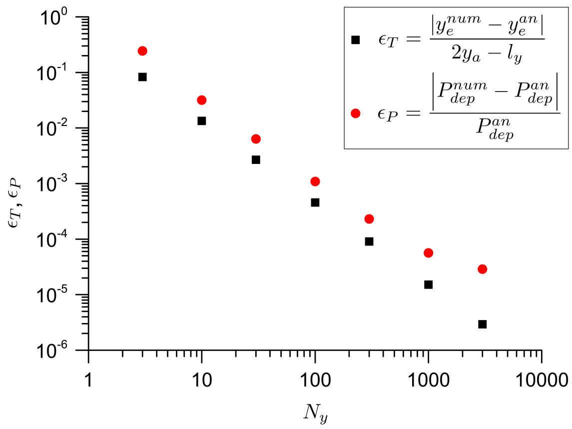

Figure 2: Dimensionless trajectory error ϵ_T at the mesh exit point and relative error ϵ_P in the summed-up deposited powers as functions of the number of quadrilateral cells in the y-direction N_y for a quarter cosine-wavelength.

References

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